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Stroboscopic Augmented Reality as an Approach to Mitigate Gravitational Transition Effects During Interplanetary Spaceflight

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Healthy astronaut vision during long duration spaceflight is critical for mission performance and human safety. During interplanetary spaceflight, periods of extreme gravitational transitions are anticipated to occur between hypergravity, hypogravity, and microgravity. Following these gravitational (g) transitions, rapid sensorimotor adaptation or maladaptation may occur which can stabilize or impair gaze control and dynamic visual acuity (DVA). The National Aeronautics and Space Administration (NASA) Human Research Program describes “Risk of Altered Sensorimotor/Vestibular Function” as a potentially significant risk following gravitational transitions. Mitigation of these effects on the visual system during these transitions (e.g., traveling to and landing on the lunar surface or Mars) will be critical for mission success (NASA, 2022).

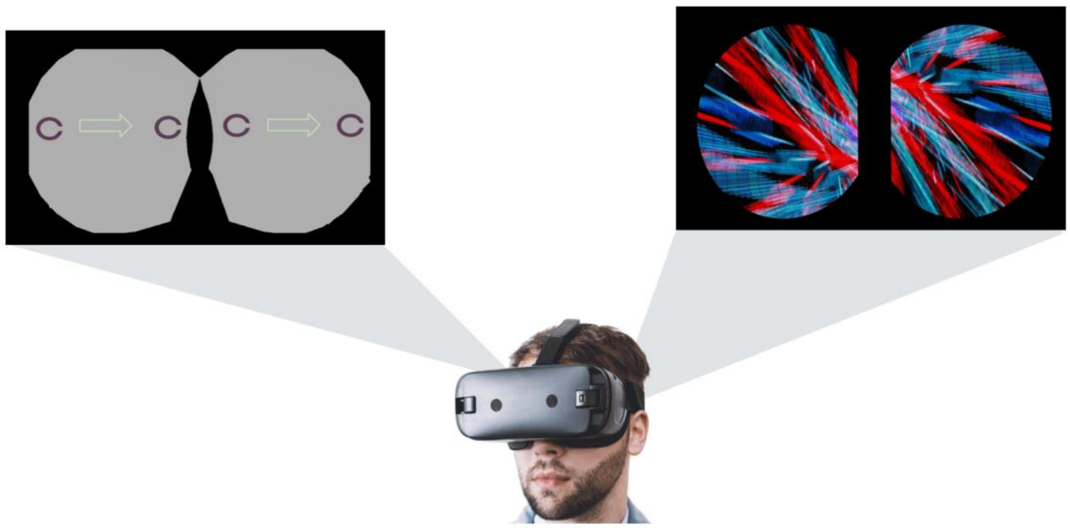
Previous reports suggest that within 24 hours after landing on Earth following long-duration spaceflight, astronauts have an average DVA decrease of 0.75 eye chart lines and some astronauts demonstrate degradation of DVA similar to terrestrial vestibular impairment (Peters et al., 2011) This significant decrease in DVA following g-transitions is likely even an underestimate, as a significant period of time elapsed prior to measurement (24 hours). These DVA impairments are particularly concerning as they may occur during the most critical phases of spaceflight (e.g., entering or exiting the gravitational fields of different celestial bodies). These g-transitions place high demand on the visual processing systems that could impair mission critical tasks.

Dynamic visual acuity (DVA) is defined as the ability to resolve details in an object that is in motion or while the observer is in motion. It is crucial for astronauts to maintain optimal DVA during mission critical task performance. DVA depends on several factors including the vestibulo-ocular reflex, visual motion processing, and catch-up saccades (Ramaioli et al., 2019). Vestibular adaptation following g-transitions remains poorly understood, as there are currently no DVA assessments being performed in space. However, many of the effects of g-transitions are known including altered sensorimotor control, blood pressure regulation, and space motion sickness (SMS) (Goswami et al., 2021). Retinal slip (when an image is improperly focused on the retina) from degradation of gaze holding and visual compensatory mechanisms can provoke symptomatic SMS. Although the severity of SMS can range from mild to more severe, nausea and vomiting could impair mission performance or have potential morbidity and mortality implications for affected astronauts and other crew members in space.

In prior work, we have developed a virtual reality (VR) based method to assess DVA as part of a larger NASA-funded endeavor for a non-intrusive ocular monitoring framework to model ocular structure and functional changes due to long-term spaceflight (Figure 1)(Ong, Tavakkoli, et al., 2022; Ong, Zaman, et al., 2022). Ocular imaging and visual assessment technology for spaceflight is highly focused on monitoring and documenting spaceflight associated neuro-ocular syndrome (SANS). SANS is a collection of neuro-ophthalmic imaging and functional changes due to the microgravity environment that includes hyperopic refractive error shifts, optic disc edema, posterior globe flattening, and choroidal folds (Lee et al., 2020) .This multimodal, head-mounted visual assessment technology might allow for frequent and broad monitoring of various functional changes to the neuro-ophthalmic system due to both prolonged microgravity exposure (i.e., SANS) as well as acute g-transition effects on DVA (Waisberg, Ong, Zaman, et al., 2022) A future terrestrial application of this visual assessment technology is to help screen for preventable blindness in developing countries (Waisberg, Ong, Paladugu, Zaman, et al., 2022; Waisberg, Ong, Paladugu, Kamran, et al., 2022).

Figure 1

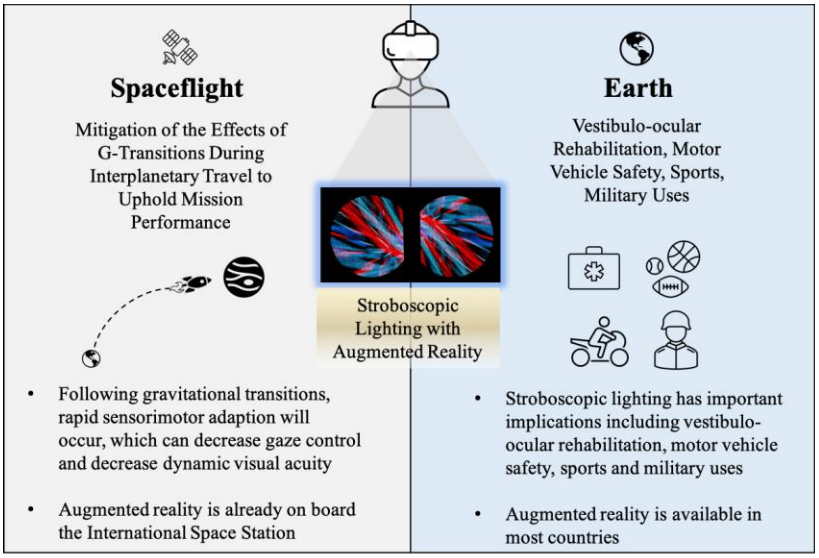
Schematic of Dynamic Visual Acuity Assessment and Stroboscopic Countermeasure in a Single Head-Mounted Display



In addition to DVA assessment, augmented reality allows for the dynamic nature of immediately introducing countermeasures within the same head-mounted system if DVA is decreased. Stroboscopic goggles have been explored to maintain and support DVA in subjects as a potential countermeasure for g-transitions and SMS (Reschke et al. 2007; Rosenberg et al., 2017) Our approach is to develop and employ stroboscopic effects in augmented reality, rather than goggles. With this novel stroboscopic approach in the augmented reality platform, we aim to develop an optimal, efficient countermeasure for degraded DVA during g-transitions. This new approach with augmented reality to mitigate g-transitions for astronauts will likely have terrestrial applications for human life on Earth including vestibulo-ocular rehabilitation and motor vehicle safety (Figure 2).

Figure 2

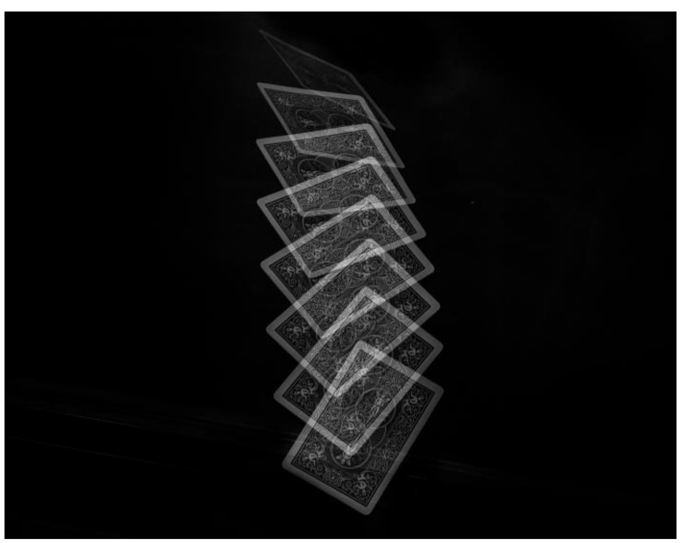
Comparing the Potential Applications of Stroboscopic Augmented Reality During Interplanetary Travel and Terrestrially



Stroboscopic visual training (SVT) is a new tool directed at enhancing visual performance and perception by performing tasks under conditions of intermittent vision (Figure 3). Although current research is very limited, previous studies have shown SVT to improve DVA, central field motion sensitivity, anticipation, processing speed, visual memory and accommodation (Wilkins et al., 2018). The proposed mechanism of SVT is that a reduction in the input of visual samples received forces an individual to use these samples more efficiently, and may make greater use of other senses, including kinaesthetic awareness (Wilkins et al., 2018).

Figure 3

Long-Exposure Stroboscopic Image of a Playing Card Being Dropped, Showcasing the Discontinuous Nature of the Image



In Table 1 (below), we summarize the existing literature surrounding stroboscopic vision that involves dynamic visual acuity or space motor sickness. In the following section, we describe our methods for integrating strobe lighting into augmented reality to evaluate if DVA can be improved, and to determine if this would be a suitable countermeasure for astronauts undergoing g-transitions.

Table 1

Table Summarizing Current Stroboscopic Literature Relating to Dynamic Visual Acuity and/or Motion Sickness

Author (Year)	Number of Subjects	Analog used to simulate vestibulo-ocular dysfuncion	Strobe Frequency	Findings
Melville et al. (1981)	7	Left-right reversing prisms	4 Hz	Stroboscopic flash prevented motion sickness and with the strobe, subjects adapted better to the reversing prisms.
Reschke et al. (2004)	1	Case report of one astronaut that experienced square wave jerks while in space.	Saccade away from followed by a corrective saccade within 200ms	Unlike most other astronauts, no decrease in postflight performance or vision impairment was seen.
Rescheke et al. (2007)	69	Visual field reversal, reading in a moving car, parabolic flight, rough seas in a small boat, reading while in the cabin of a UH60 Black Hawk Helicopter	4-8 Hz	Stroboscopic illumination reduces the severity of motion sickness symptoms.
Holliday (2013)	16	None	Ranging from 25-900 ms of occlusion, and transparent for 100ms	Stroboscopic training increased DVA and ball catching performance.
Webb et al. (2013)	18	Nauseogenic helicopter flight	8 Hz	Self-reported nausea scores were lower, and better psychomotor vigilance task performance was seen with stroboscopic cabin illumination.
Rosenberg et al. (2017)	20	Minifying lenses	4 Hz	With stroboscopic illumination, fewer subjects experienced motion sickness. Shutter glasses with a frequency of 4 and 8 Hz with a dwell time of 10-20ms, had the same efficacy as a strobe light.

Methods

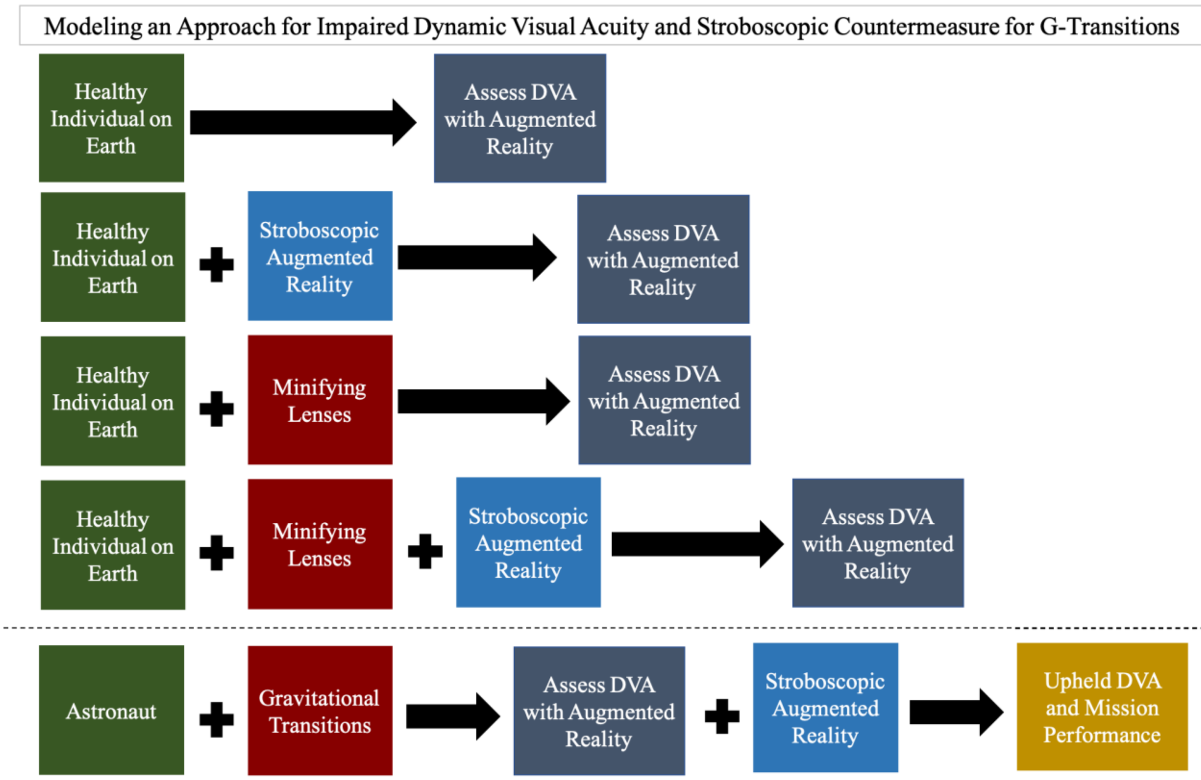
Hardware

Various augmented reality (AR) headsets can be used to implement a strobe effect. These headsets include the Varjo XR-3, which has a field of view of 115 degrees, integrated 200 Hz eye tracking, and pixel density of over 70 pixels per degree. UnrealEngine 4 version 4.24 was used to build the stroboscopic effect, and SteamVR was used to experience the augmented reality content. The augmented reality headset will alternate between clear and opaque states at 3 different frequencies: 6 Hz (most visual samples received), 3 Hz, and 1 Hz (least visual samples received). These frequencies are similar to the frequencies used in previous stroboscopic studies, however, to our knowledge this has never previously been tested in an augmented reality setting.

Assessment Design

Our modeled approach for assessment using VR compares DVA with and without the stroboscopic effect (Figure 4). As a terrestrial analog to simulate the impaired vestibulo-ocular state of a returning astronaut, healthy participants wore minifying lenses (discussed below). DVA was measured binocularly and conducted with Landolt C optotypes. During this test, the Landolt C optotype was orientated in 8 possible directions, and participants responded using numpad keys to indicate the direction of the gap in the “C.” If the participant identified the location of the gap correctly, the character size was decreased logarithmically. Conversely, following an incorrect response the character size increased logarithmically. Both tests were conducted on the same day, during the same session to minimize potential confounding variables.

Figure 4
Modeled Approach to Detect Changes in DVA in Healthy Individuals on Earth, Simulate Decreased DVA, and Assessment with the Stroboscopic Augmented Reality (Top). Integration of Approach for Astronauts Undergoing Gravitational Transitions for Future Interplanetary Spaceflight



Data Analysis

Four dependent variables were assessed in 4 groups (healthy individuals without headset vs healthy individuals with stroboscopic AR vs. heathy individuals with minifying lenses vs. heathy individual with minifying lenses and stroboscopic AR). Dependent variables in the study were DVA in the horizontal axis, DVA in the vertical axis, focal length of the minifying lens (or magnitude of minification), and strobe duration. These variables were analyzed with SPSS software using a 4 group by 2 testing session repeated measures ANOVA. Mean DVA (LogMAR) and standard deviation were calculated for each group. To determine if dependent variables reached statistical significance, confidence intervals were used. In addition, independent t-tests were run to compare the various groups with a significance level of $p < 0.05$.

Potential Terrestrial Analog for Gravitational Transitions with Augmented Reality

In our study, minifying lenses were worn by healthy subjects to simulate the decrease in dynamic visual acuity that is associated with gravitational transitions. The minifying lenses caused retinal slip, which then induced a state of vestibulo-ocular adaptation to occur with the goal of stabilizing images onto the retina (Schubert & Migliaccio, 2019) While wearing minifying lenses, visual inputs also appeared to move less than normal, which required a lesser vestibulo-ocular response to compensate for the decreased movement (Gonshor & Jones, 1976) Sehizadeh (2005) found that by placing a lens in front of an eye with a minifying power of 6%, a 6% decrease in the vestibulo-ocular gain was noted.

Vestibulo-ocular gain is given by the equation (Equation 1):

Equation 1

Equation of Vestibulo-Ocular Gain for Minifying Power as a Basis for a Potential Terrestrial Analog for Gravitational Transitions

$$\text{Vestibulo-ocular gain} = \frac{Eye\ rotation\ amplitude}{Head\ rotation\ amplitude}$$

Ideally, vestibulo-ocular gain should be equal to 1 and significant deviations from this can result in visual instability, imbalance and oscillopsia (Sehizadeh 2005). To adapt to a new gain, the process of vestibulo-ocular adaptation occurs. This adaptation is a form of motor learning and requires both vestibular and visual inputs (Sehizadeh 2005). The adaptation process involves retinal slip signals reaching the inferior olivary nucleus, then is transmitted to the vestibulo-cerebellum, which signals the vestibular nucleus and alters the floccular target cell response to vestibular input (Rosenberg et al. 2017). A part of this research is to also develop potential minifying lens effects with augmented reality as a terrestrial analog for gravitational transitions. This AR-based simulation of minifying lens effects will allow for smoother integration of the g-transition effects and the stroboscopic countermeasure in the same head-mounted display.

Terrestrial Analogue of SMS

Persistent Postural-Perceptual Dizziness (PPPD) is the terrestrial equivalent of SMS and occurs from sensory-motor mismatch of the vestibulo-ocular system. This condition is characterized by oscillopsia and chronic dizziness which increases with movements or when exposed to complex visual stimuli. For patients with PPPD, physical examinations, neuroimaging and laboratory testing are all within normal limits. Pre-disposing factors are believed to be neurotic personality traits and pre-existing anxiety (Popkirov et al., 2018). Current treatments for PPPD have the goal of re-adapting the vestibulo-ocular system and include: vestibular habituation exercises, cognitive-behavioural therapy and medications such as selective serotonin reuptake inhibitors (SSRIs) and serotonin norepinephrine reuptake inhibitors (SNRIs) (Popkirov et al., 2018).

Discussion

G-transitions have previously been reported to cause maladaptation leading to altered blood pressure, cardiorespiratory performance, SMS, and musculoskeletal changes. Altered sensorimotor and vestibular function is another significant risk that remains poorly understood as no DVA assessment is currently performed in space. This risk will be even more significant during the Mars 2030 mission, as astronauts will be exposed to a longer period in microgravity (1.5 years) which will lead to greater sensorimotor adaptations and the physiological response and g-transition when landing on Mars will be significant. To combat this potential issue, NASA's Human Research Program recommended that countermeasures be developed to mitigate the effects of g-transitions on astronauts (SM-202) (NASA, 2022). We believe that this stroboscopic AR approach can potentially serve as such a countermeasure by improving DVA and reducing SMS in astronauts.

Although current stroboscopic studies are limited, an early review of the literature by Wilkins and Appelbaum (2020) was promising and found that stroboscopic visual training can enhance visual and perceptual skills, particularly relating to fast, foveal vision. This same review found that even though current studies used varying strobe rates and differing protocols for stroboscopic visual training, the same beneficial effects were seen. Recently, several studies have found that practice in stroboscopic visual conditions can improve sports-specific skills in soccer (Wilkins et al., 2018), baseball (Clark et al., 2012), ice-hockey(Mitroff et al., 2013) and badminton (Hülsdünker et al., 2019). With suboptimal visual information available in stroboscopic conditions, it is believed that visual-cognitive processes are then driven to adapt and improve, akin to the effects of how altitude training increases endurance (Ballester et al., 2017) Astronauts practicing mission-specific skills in stroboscopic conditions might be able to significantly improve performance during interplanetary missions, particularly during g-transition effects.

An interest in the application of stroboscopic lighting in spaceflight first developed following an astronaut who returned following 140 days orbit and showed a particularly good recovery post-flight (no decrease in postflight performance or vision impairments) (Reschke et al., 2004). This astronaut had square wave jerks, consisting of a saccade away from the fixation point, followed by a corrective saccade within 200 milliseconds. Reschke et al. (2004) hypothesized that the astronaut's square wave jerks produced a strobe-like effect which was responsible for the increased post-flight performance that was seen.

Rescheke et al. (2004) later demonstrated that SMS onset can be improved by stroboscopic vision goggles. SMS commonly occurs as a result of sensory mismatch (including retinal slip). When images are not stabilized on the retina (i.e., retinal slip) this sensory mismatch results in symptomatic SMS. The proposed mechanism for stroboscopic goggles resolving motion sickness is that the strobe lighting provides brief snapshots of the visual environment, thus preventing retinal slip. To simulate the vestibulo-ocular state of returning astronauts, a study in 2017 by Rosenberg et al. conducted a study where a group of 20 healthy subjects wore minifying lenses. While wearing these lenses, the DVA of these healthy individuals decreased 31.5%. However, when these individuals then wore strobe goggles, DVA was only 6.9% worse. While wearing strobe goggles only, DVA improved 8.8%. This suggests that stroboscopic lighting can be an efficient countermeasure for vestibulo-ocular adaptations. Another consideration with this approach is the effect of SANS on vision in addition to decreased dynamic visual acuity. Head-down tilt bed rest is a ground-based analog that has been utilized to study SANS, mimicking the cephalad fluid shifts observed in microgravity. Strict head-down tilt bed rest has been observed to produce chorioretinal folds and optic disc edema, both signs of SANS observed in astronauts after long-duration spaceflight. Minifying lenses in addition to head-down tilt bed rest may provide further insight into what astronauts may experience during exploration mission with both prolonged exposure to microgravity on the neuro-ophthalmic system and gravitational transitions.

Aside from acting as a potential g-transition countermeasure in spaceflight, stroboscopic augmented reality can have significant implications terrestrially as a countermeasure for vestibular dysfunction. It is estimated that 35.4% of those aged over 40 years in the United States have vestibular dysfunction, which significantly increases the likelihood of falling. Amongst older individuals, falls are associated with significant morbidity, affecting mobility, autonomy and represents one of the leading causes of death. Even after adjusting for an ageing population, the incidence of injuries induced by falls has increased significantly over the past 25 years. Stroboscopic augmented reality can potentially serve as a preventative measure to help reduce incidence of these injures.

Stroboscopic augmented reality may also serve as a useful non-pharmacologic countermeasure against terrestrial motion sickness. Current treatment regimens for motion sickness typically involve the usage of medications such as antihistamines, with nonsedating antihistamines having a lower efficacy in reducing symptoms. This class of drugs can cause unwanted side-effects including drowsiness, impair reaction times and judgement times. Stroboscopic augmented reality can potentially allow individuals in high-risk occupations to continue to perform at high levels while alleviating motion sickness symptoms.

Conclusion

To our knowledge, this work is the first proposed application of the stroboscopic effect in AR as a possible countermeasure for SANS and SMS. With its ease of use and lightweight design, stroboscopic augmented reality has the potential to be a crucial countermeasure in spaceflight, if its efficacy to improve DVA and/or reduce the symptoms of SMS can be shown. Currently, there are considerable variations in studies that look at stroboscopic effects on vision, which limit our ability to draw conclusions on the topic. To fully investigate the efficacy of stroboscopic vision as a dynamic visually acuity countermeasure, we must first find: the most effective strobe rate; determine if individuals eventually adapt to the strobe; and examine the effectiveness of stroboscopic vision to treat other vestibulo-ocular problems. Stroboscopic augmented reality will likely also have important implications on Earth including vestibulo-ocular rehabilitation, motor vehicle safety, sports, and military uses.

Conflict of Interest Statement:

On behalf of all authors, the corresponding author states that there is no conflict of interest

References

Rafael, B., Huertas, F., Uji, M., & Bennett, S. J. (2017). Stroboscopic vision and sustained attention during coincidence-anticipation. *Scientific Reports, 7*(1), 17898.

Clark, J. F., Ellis, J. K., Bench, J., Khoury, J., & Graman, P. (2012). High-performance vision training improves batting statistics for University of Cincinnati baseball players. *PloS One, 7*(1), e29109.

Gonshor, A., & Jones, G. M. (1976). Short-term adaptive changes in the human vestibulo-ocular reflex arc. *The Journal of Physiology, 256*(2), 361–79.

Goswami, N, White, O., Blaber, A., Evans, J., van Loon, J., & Clement, G. (2021). Human physiology adaptation to altered gravity environments. *Acta Astronautica, 189*, 216–21.

Holliday, J. (2013). *Effect of stroboscopic vision training on dynamic visual acuity scores: Nike Vapor Strobe® Eyewear*. Utah State University.

Hülsdünker, T., Rentz, C., Ruhnow, D., Käsbauer, H., Strüder, H. K., & Mierau, A. (2019). The effect of 4-week stroboscopic training on visual function and sport-specific visuomotor performance in top-level badminton players. *International Journal of Sports Physiology and Performance, 14*(3), 343–50.

Bloomberg, J. J., Reschke, M. F., Clément, G. R., Clement, Mulavara, A. P., & Taylor, L. C. (2016). Evidence report: Risk of impaired control of spacecraft/associated systems and decreased mobility due to vestibular/sensorimotor alterations associated with spaceflight. *Human Research Program Human Health Countermeasures Element 2016.*

Jones, G. M., & Mandl, G. (1981). Motion sickness due to vision reversal: Its absence in stroboscopic light. *Annals of the New York Academy of Sciences*. 374(1 Vestibular an), 303–11.

Lee, A. G. Mader, T. H., Gibson, C. E., Tarver, W., Rabiei, P., Riascos, R. F., Gladamez, L. A., & Brunstetter, T. (2020). Spaceflight associated neuro-ocular syndrome (SANS) and the neuro-ophthalmologic effects of microgravity: A review and an update. *NPJ Microgravity, 6*(1), 7.

Mitroff, S. R., Friesen, P., Benett, D., & Yoo, H. (2013). Enhancing ice hockey skills through stroboscopic visual training: A pilot study. *Athletic Training & Sports Health Care, 5*(6), 261–64.

Ong, J., Tavakkoli, A., Zaman, N., Kamran, S. A., Waisberg E, Gautam N, & Lee, A. G. (2022). Terrestrial health applications of visual assessment technology and machine learning in spaceflight associated neuro-ocular syndrome. *NPJ Microgravity, 8*(1), 37. doi:10.1038/s41526-022-00222-7

Ong, J., Zaman, N., Kamran, S. A., Waisberg, E., Tavakkoli, A., Lee, A. G., & Webster, M. (2022). A multi-modal visual assessment system for monitoring spaceflight associated neuro-ocular syndrome (SANS) during long duration spaceflight. *Journal of Vision, 22*(3), 6.

Peters, B. T., Miller, C. A., Brady, R. A., Richards, J. T., Mulavara, A. P., & Bloomberg, J. J. (2011). Dynamic visual acuity during walking after long-duration spaceflight. *Aviation, Space, and Environmental Medicine, 82*(4), 463–66.

Popkirov, S., Staab, J. P., & Stone, J. (2018). Persistent postural-perceptual dizziness (PPPD): A common, characteristic and treatable cause of chronic dizziness. *Practical Neurology, 18*(1), 5–13.

Ramaioli, C., Cuturi, L. F., Ramat, S., Lehnen, N., & MacNeilage, P. R. (2019). Vestibulo-ocular responses and dynamic visual acuity during horizontal rotation and translation. *Frontiers in Neurology, 10*, 321.

Reschke, M., Somers, J. T., Leigh, S. R., Krnavek, J. M., Kornilova, L., Kozlovskaya, I., Bloomberg, J. J., & Paloski, W. H. (2004). Sensorimotor recovery following spaceflight may be due to frequent square-wave saccadic intrusions. *Aviation, Space, and Environmental Medicine, 75*(8), 700–704.

Reschke, M. F., Somers, J. T., Ford, G., & Krnavek, J. M. (2007). *Stroboscopic vision as a treatment for space motion sickness*. https://www.researchgate.net/publication/228841393_Stroboscopic_Vision_as_a_Treatment_for_Retinal_Slip_Induced_Motion_Sickness

NASA. (2022). Risk of altered sensorimotor/vestibular function impacting critical mission tasks. *NASA HRP*. https://humanresearchroadmap.nasa.gov/risks/risk.aspx?i=88 (February 23, 2022).

Rosenberg, M. J. F., Kreutzberg, G. A., Peters, B. T., & Reschke, M. F. (2017). Stroboscopic goggles as a countermeasure for dynamic visual acuity and landing sickness in crewmembers returning from long-duration spaceflight. *NASA*. https://ntrs.nasa.gov/citations/20160013635

Schubert, M. C., & Migliaccio, A. A. (2019). New advances regarding adaptation of the vestibulo-ocular reflex. *Journal of Neurophysiology, 122*(2), 644–58.

Sehizadeh, M. (2005). *Monocular adaptation of vestibulo-ocular reflex (VOR)*. University of Waterloo.

Waisberg, E., Ong, J., Zaman, N., Kamran, S. A., Lee, A. G., & Tavakkoli, A. (2022). Head-mounted dynamic visual acuity for g-transition effects during interplanetary spaceflight: Technology development and results from an early validation study. *Aerospace Medicine and Human Performance, 93*(11), 800–805.

Waisberg, E., Ong, J., Paladugu, P., Kamran, S. A., Zaman, N., Tavakkoli, A & Lee, A. G. Advances in machine learning to detect preventable causes of blindness. *Eye* (2022). https://doi.org/10.1038/s41433-022-02354-2

Waisberg, E., Ong, J., Paladugu, P., Zaman, N., Kamran, S. A., Lee, A. G., & Tavakkoli, A. (2022). Optimizing screening for preventable blindness with head-mounted visual assessment technology. *Journal of Visual Impairment & Blindness, 116*(4), 579–81.

Webb, C. M., Estrada, A., & Athy, J. R. (2013). Motion sickness prevention by an 8-Hz stroboscopic environment during air transport. *Aviation, Space, and Environmental Medicine*, *84*(3), 177–83.

Wilkins, L., & Appelbaum, L. G. (2020). An early review of stroboscopic visual training: Insights, challenges and accomplishments to guide future studies. *International Review of Sport and Exercise Psychology, 13*(1), 65–80.

Wilkins, L., Nelson, C., & Tweddle, S. (2018). Stroboscopic visual training: A pilot study with three elite youth football goalkeepers. *Journal of Cognitive Enhancement, 2*(1), 3–11.